Searches for Dark Matter candidates with electron beams at JLAB

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Hampton University/Jefferson Lab Theory Center

6th Patras Workshop on Axions, WIMPs and WISPS

University of Zurich, Physics Institute, July 5-9, 2010

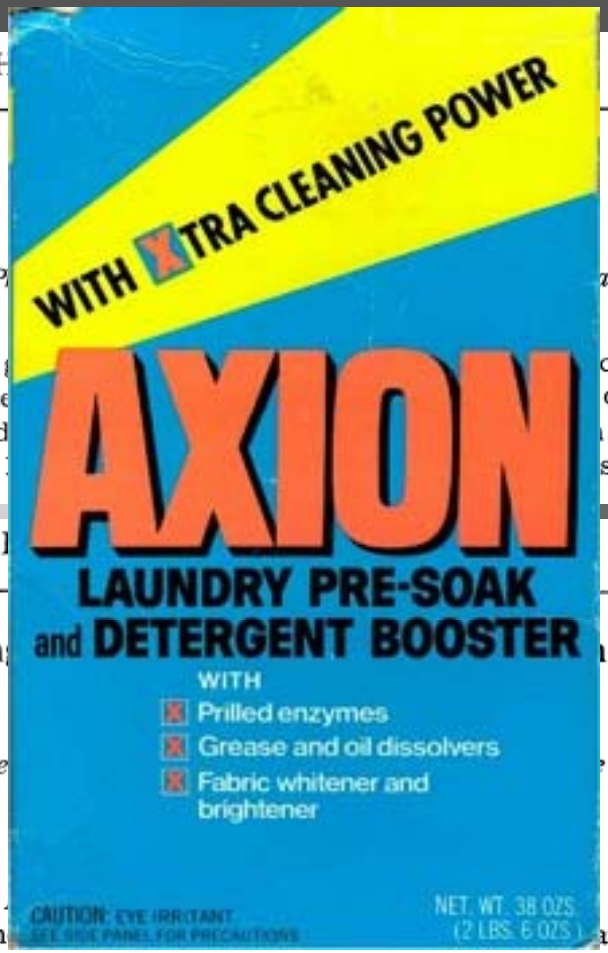
Plan of Talk

- Laser-based laboratory search for axion-like particles (LIPSS at JLAB)
- New astrophysics data
  - Implications for new particles at MeV-Gev scale and accelerator-based searches
  - What electron accelerators can do?
    - APEX, ...
    - Beam-dump

What is Dark Matter? Particle interpretation:

(Still unknown) elementary particles that interact only weakly with `normal' matter

One of the candidates: **Axion** - also addresses a *strong CP problem* in QCD



VOLUME 40, NUMBER 4 — 23 JANUARY 1978

Lyman Laboratory of P… …assachusetts 02138

It is pointed out that a … …ced in order to pre-serve the parity and time… …despite the effects of instantons, would lead… …," with mass rough-ly of order 100 keV to 1 … …sed.

VOLUME 40, NUMBER 5 — 30 JANUARY 1978

Problem of Stron… …ce of Instantons

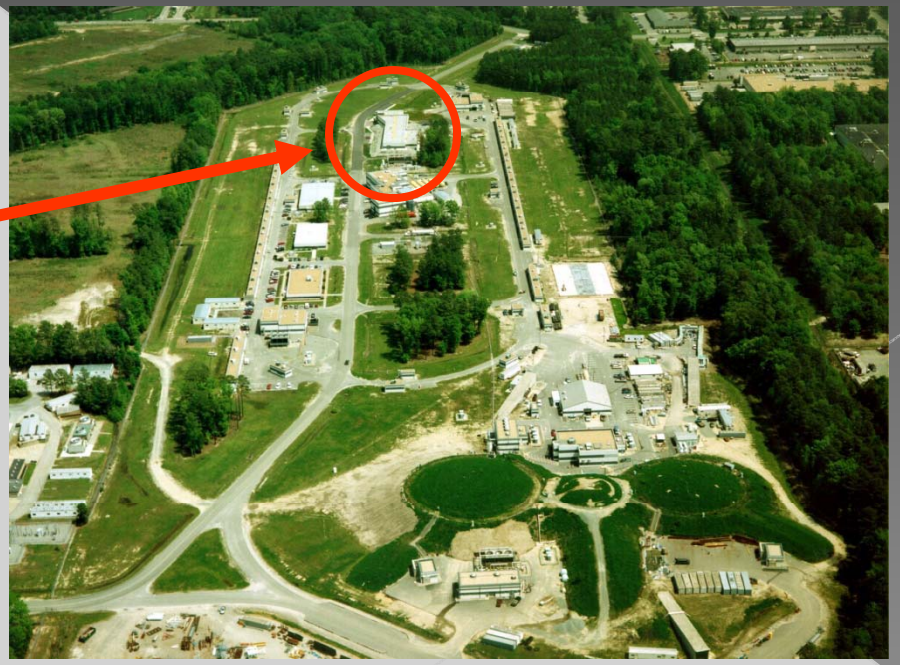
Columbia University, Ne… …for Advanced Studies,

The requirement that … …color gauge theory of strong interactions with… …analyzed. Several possibilities are identified, including one which would give a remarkable new kind of very light, long-lived pseudoscalar boson.

Jefferson Lab is Located in Newport News, Virginia

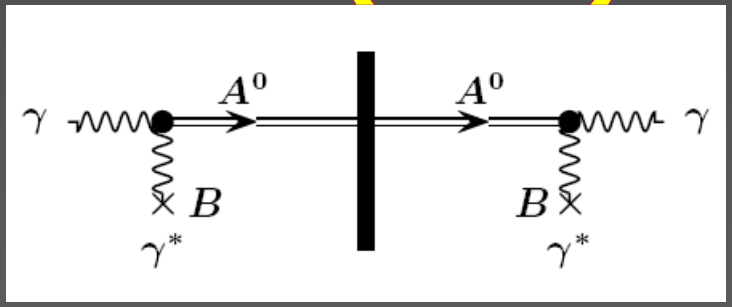
JLAB's Free Electron Laser

Produced up to 14kW of continuous light at 1.6 micron wavelength

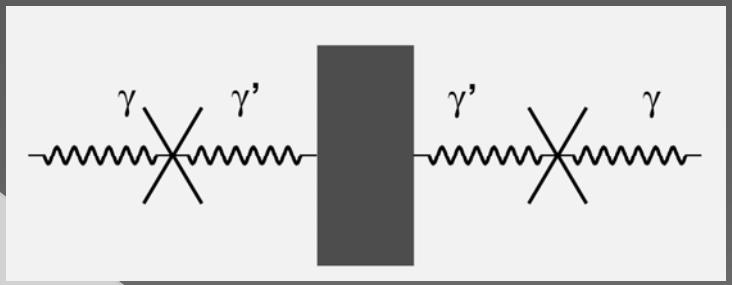


Photon Regeneration in `Light Shining through a Wall' (LSW)

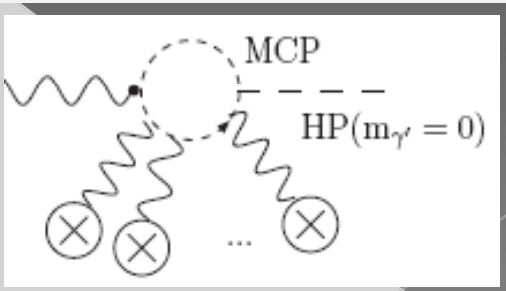
- Photon-axion conversion in presence of magnetic field



- Photon-(massive) paraphoton oscillation (no magnetic field)

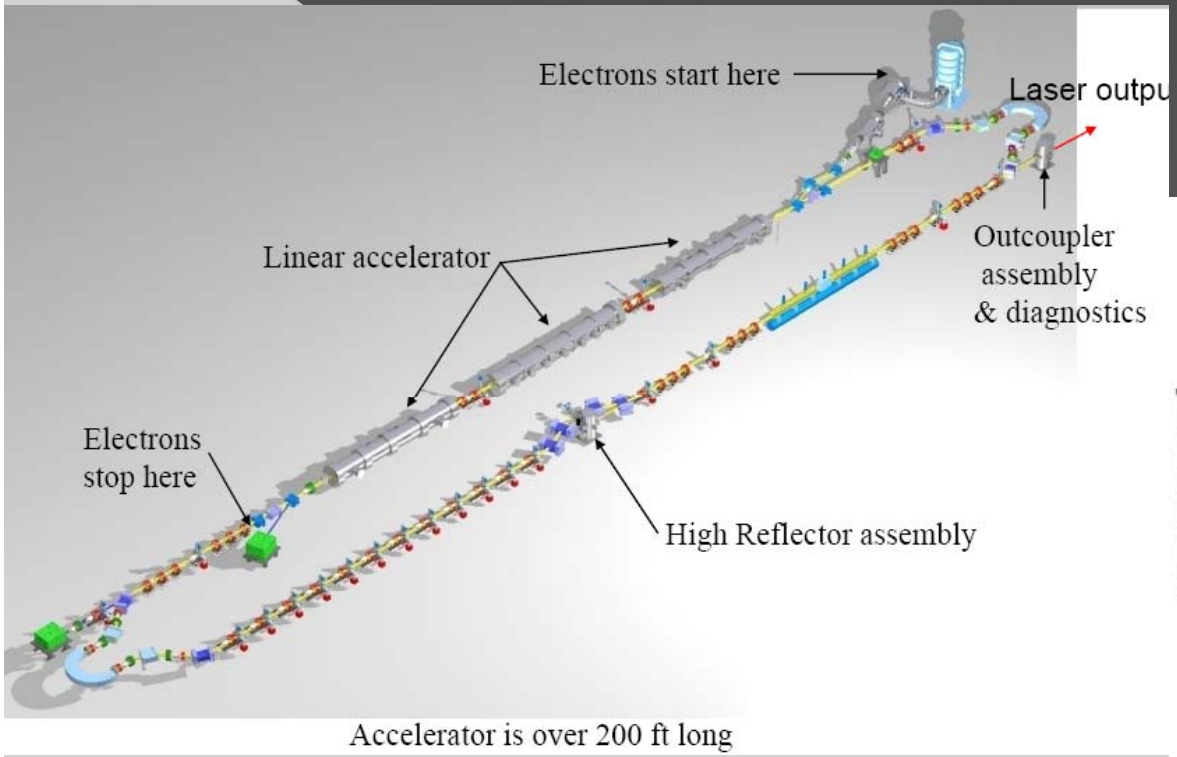


- Photon-(massless) paraphoton conversion in magnetic field via quantum loop of mini-charged particles (MCP)



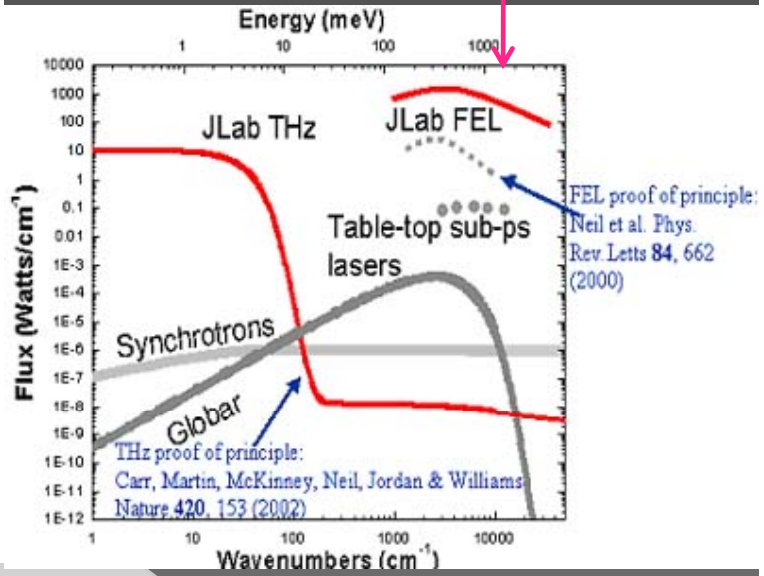
Experimental that use LSW: LIPSS(Jlab, this talk) , BFRT (BNL), BMV(LULI), GammeV (Fermilab), ALPS(DESY), OSCAR (CERN), PVLAS (INFN)

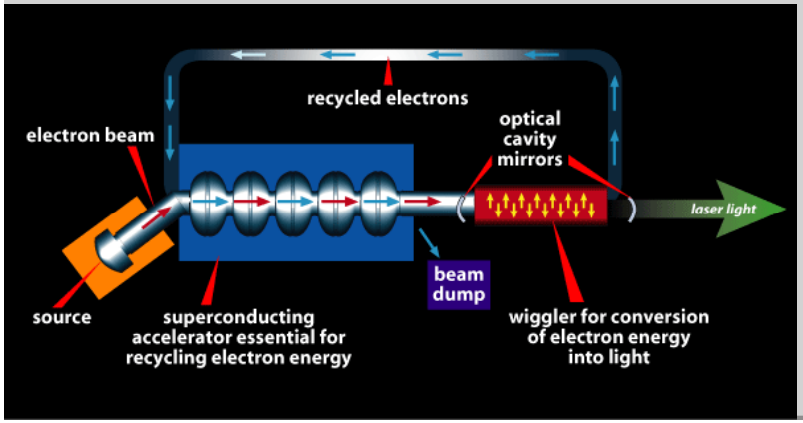
JLAB FEL: Used for LIPSS experiment



Accelerator is over 200 ft long

LIPSS IR run at 0.935 micron





150 fs wide pulses

75 MHz rep rate

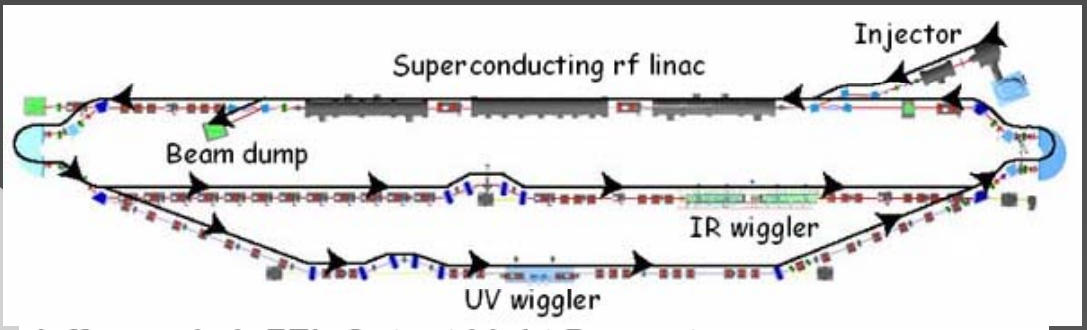
100 % df

935. +/- 005 nm

200 watts avg power

>99% linearly polarized

More info on JLAB FEL



Jefferson Lab FEL Output Light Parameters

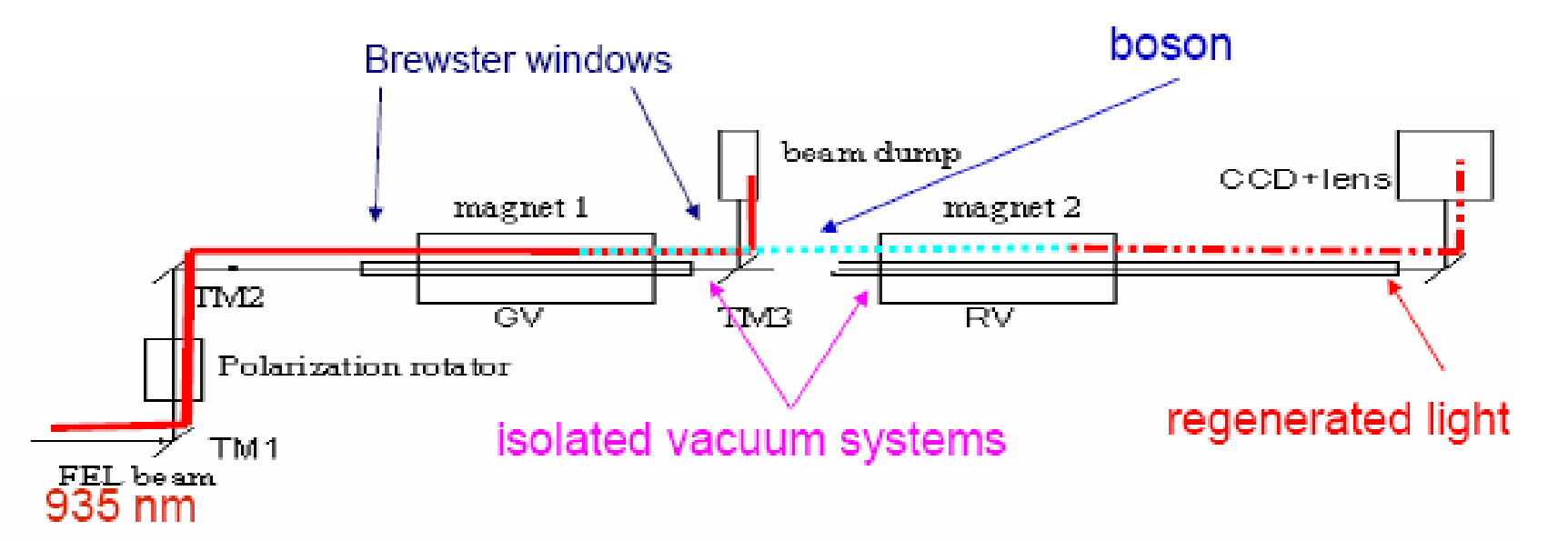
	IR Branch	UV Branch
Wavelength range (microns)	1.5 - 14	0.25 - 1
Bunch Length (FWHM psec)	0.2 - 2	0.2 - 2
Laser energy / pulse (microJoulesJ)	100 - 300	25
Laser power (kW)	> 10	> 1
Repetition Rate (cw operation, MHz)	4.7 - 75	4.7 - 75

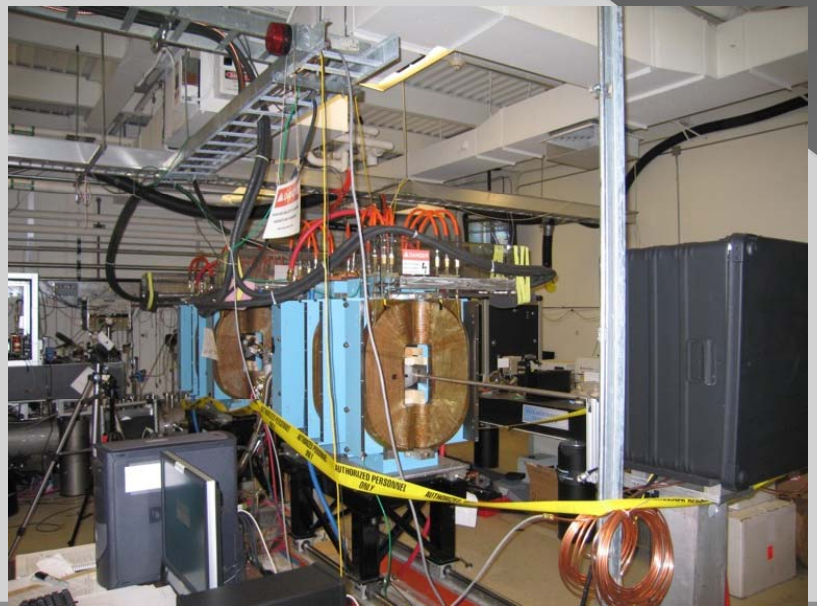
Jefferson Lab FEL Electron Beam Parameters

Energy (MeV)	80-200	200
Charge per bunch (pC)	135	135
Average current (mA)	10	5
Peak Current (A)	270	270
Beam Power (kW)	2000	1000
Energy Spread (%)	0.50%	0.13%
Normalized emittance (mm-mrad)	<30	<11
Induced energy spread (full)	10%	5%

See G. Neil et al., NIM A 557, 9 (2006); www.jlab.org/FEL

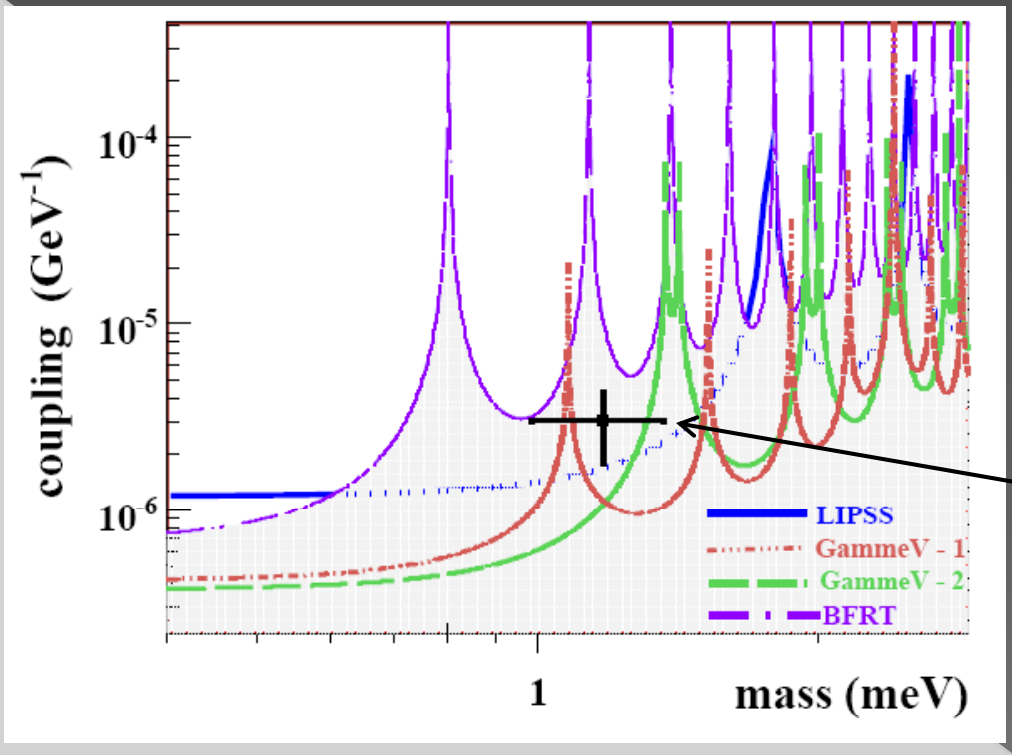
LIPSS experiment schematic





LIPSS Result on Axion-Like Particle

AA et al (LIPSS Collab), Phys Rev Lett 101, 120401 (2008)



PVLAS'05 (now disclaimed)

- No signal observed, regions above the curves are excluded by the experiment(s) at 95%CL
- Scalar coupling probed (`B^2' interaction)

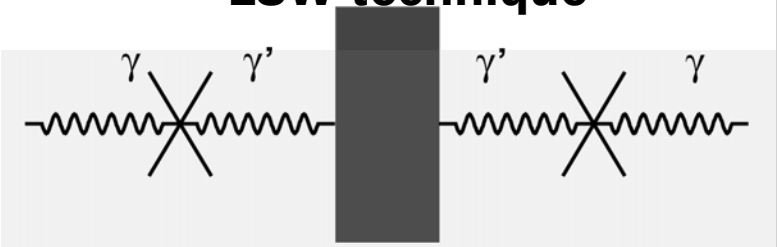
New Constraint on Photon Paraphoton Mixing

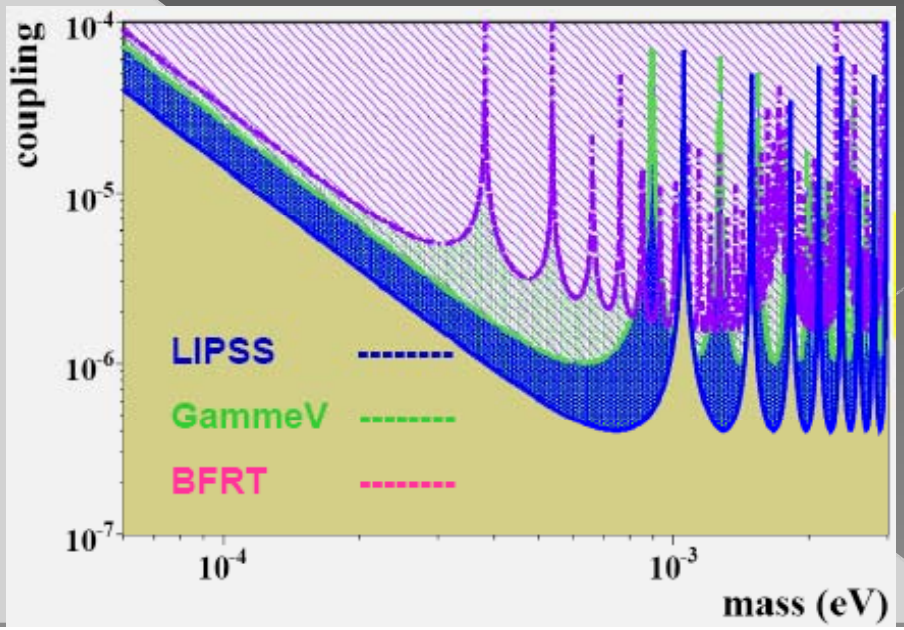
- Hidden-sector $U(1)_H$ symmetry: Paraphotons
  L.B. Okun, Sov Phys JETP 56, 502 (1982); B. Holdom, Phys Lett B 166, 196 (1986) "**Ho**ldom's **Bo**son" or HoBo
  - For the latest, see Ahlers et al, PRD 78, 075005 (2008) ; Abel et al, JHEP07, 124 (2008)

$$L_{mix} = -\frac{1}{2}\chi F^{\mu\nu} B_{\mu\nu}$$

$$P = 16\chi^4 \left[\sin\left(\frac{\Delta k L_1}{2}\right) \sin\left(\frac{\Delta k L_2}{2}\right) \right]^2$$

LSW technique

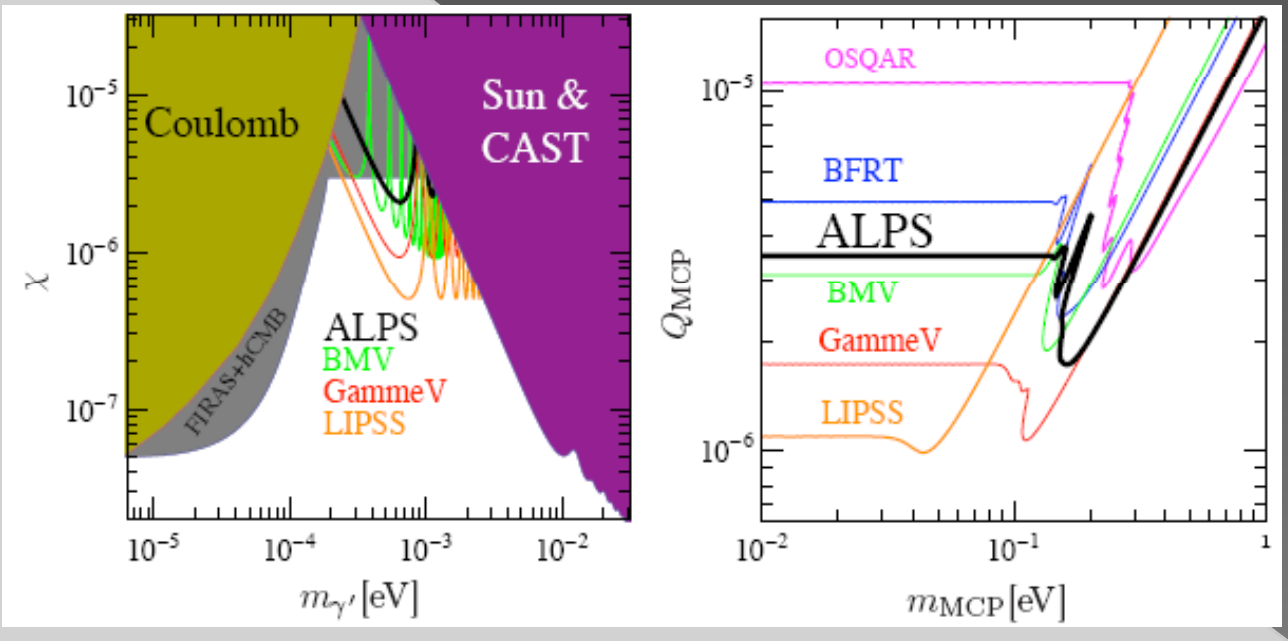




- AA et al, Phys.Lett.B 679, 317 (2009) LIPSS observed no oscillations
- Best LSW constraints due to high initial photon flux
- Region above the curves excluded at 95% CL

Photon-Paraphoton Mixing

- LIPSS results Phys.Lett. B679, 317(2009) vs other constraints:
  - As of 2009, achieved the highest sensitivity in milli-eV mass range (plot compiled in arXiv:0905.4159)



- Also leads to a new constraint on mini-charged particle (MCP) mass and charge, see formalism in Ahlers et al, PRD 78, 075005 (2008) ;
- New results from ALPS: Phys. Lett.B 689:149-155,2010.

Dark Forces Workshop

Searches for New Forces at the GeV-scale

SLAC, September 24th to 26th, 2009

Theoretical models related to dark matter have proposed that there are long-range forces mediated by new gauge bosons with masses in the MeV to GeV range and very weak coupling to ordinary matter. The experimental constraints on the existence of these new gauge bosons are quite weak. This workshop will bring together theorists and experimentalists to stimulate progress in searching for these "dark forces" in three arenas:

•New fixed-target experiments at electron and proton accelerators such as JLab, SLAC, and Fermilab;
•Searches at high-luminosity e+e- experiments, including BaBar, BELLE, CLEO-c, KLOE, and BES-III;
•Searches at the Tevatron experiments

Talks available at http://www-conf.slac.stanford.edu/darkforces2009/

Data

- Cosmics: PAMELA, Fermi, ATIC, HESS, AMS, ACTs, WMAP, Planck...
- Direct: EDELWEISS, CDMS, XENON, CRESST, ZEPLIN, XMASS, DRIFT, ArDM, DAMA/LIBRA
- Production: LHC/Tevatron, Electron-positron colliders (DAFNE, B-factories) **Fixed Target, Beam dump**

Motivating Dark Forces

- A wealth of anomalies can be explained by the presence of a new, dark force
- Single ingredient: new dark force at ~ GeV addresses key issues
  - Large excitation cross section for INTEGRAL
  - Hard leptons/no antiprotons for PAMELA/Fermi
  - Large Annihilation cross section
  - Excited states for DAMA/INTEGRAL
- Can be tested in experiment

Searching for Dark Forces in Electron Scattering Experiments on Fixed Targets

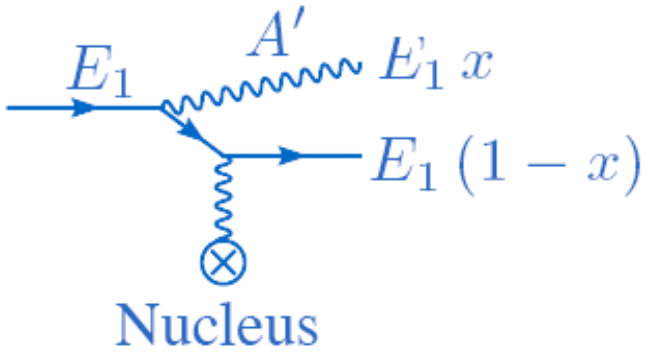
- BEST paper, Phys.Rev.D80:075018,2009

- Dark gauge boson A´ mixing with photon, Mass $m_{A'}$ = 1 MeV – few GeV

- This vertex allows A´ production in any charged-particle scattering.

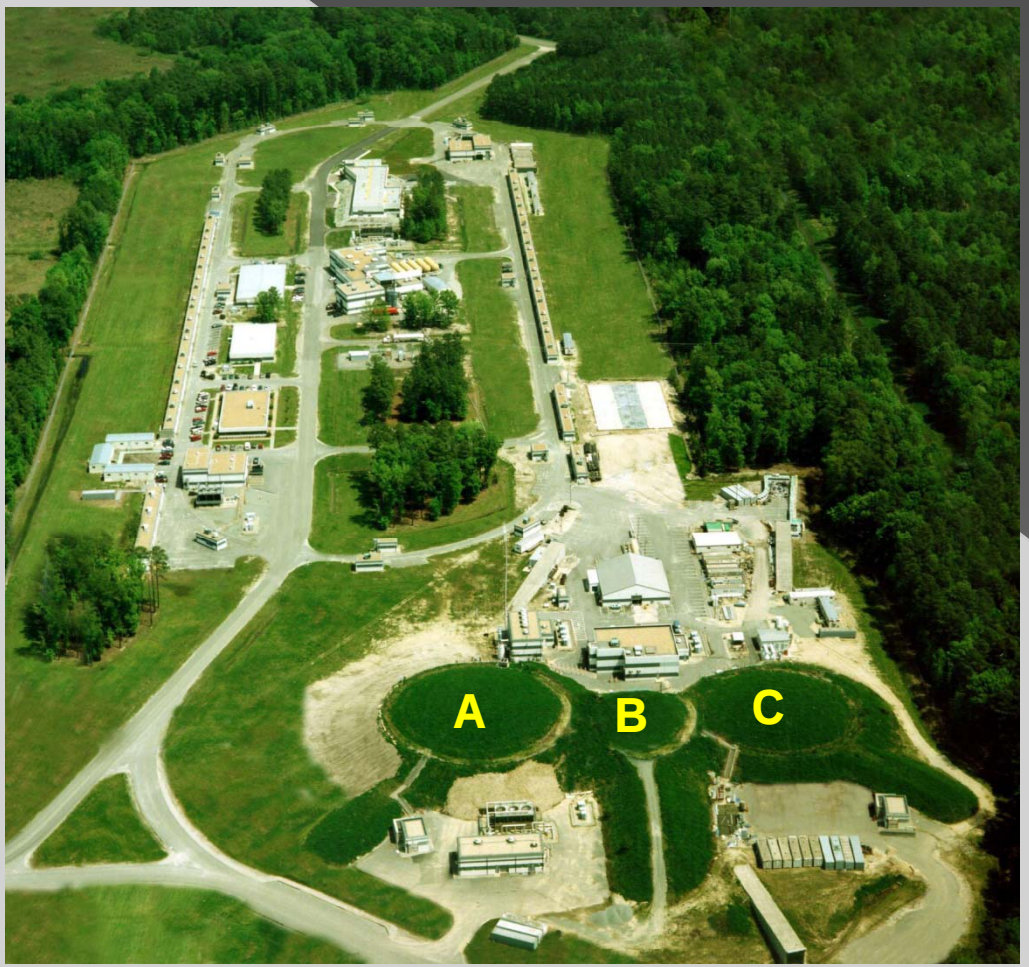
- Assume A´ decays (only) through photon mixing, i.e. to e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, etc. depending on mass $c\tau \sim (m_{A'}\epsilon^2)^{-1}$

Fixed-Target



$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

CEBAF Accelerator



- Re-circulating linac design
- Up to 5 pass, 0.3 to 1.2 GeV per pass.
- 6.0 GeV max beam energy
- 100% duty cycle
  - 2ns microstructure
- $\Delta E/E < 1 \cdot 10^{-4}$ (Halls A & C)
- Beam polarization up to 85%
- 180 μA max current
- CEBAF energy will be doubled to 12GeV after 2012

Constraints on mass vs coupling for A'

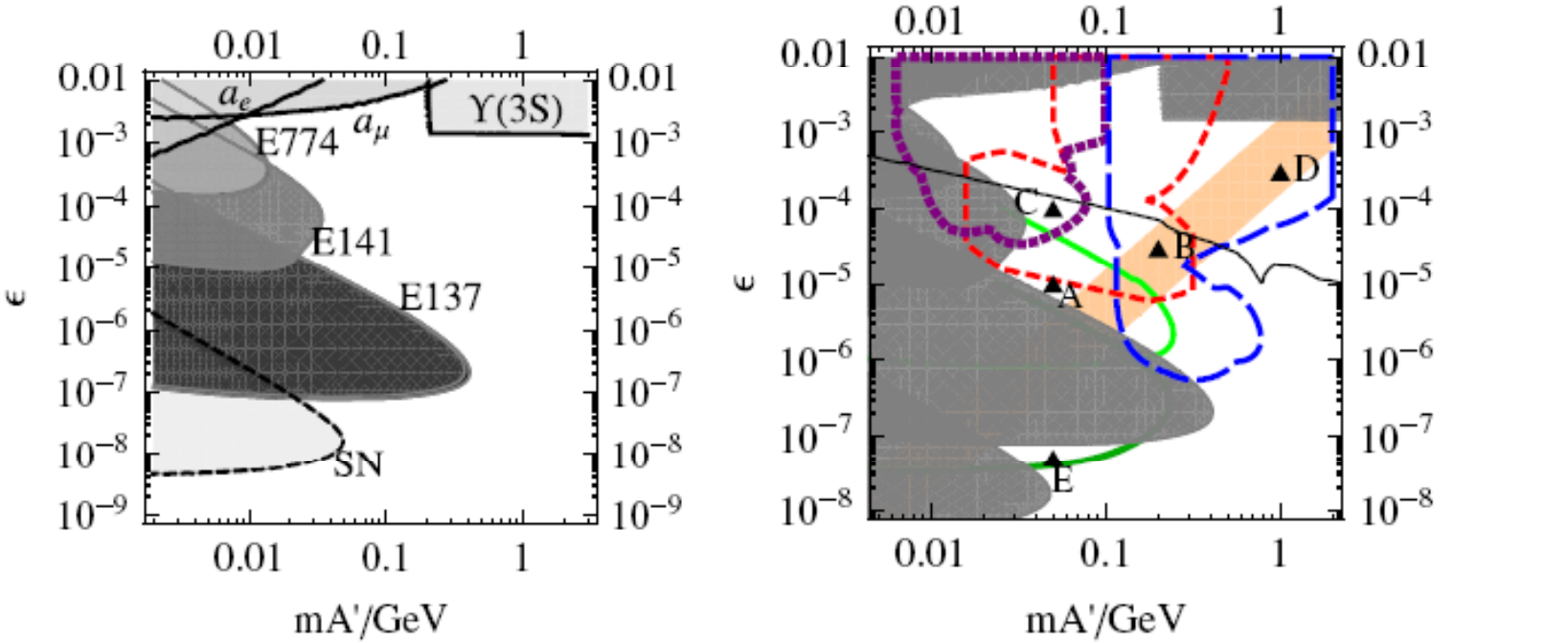
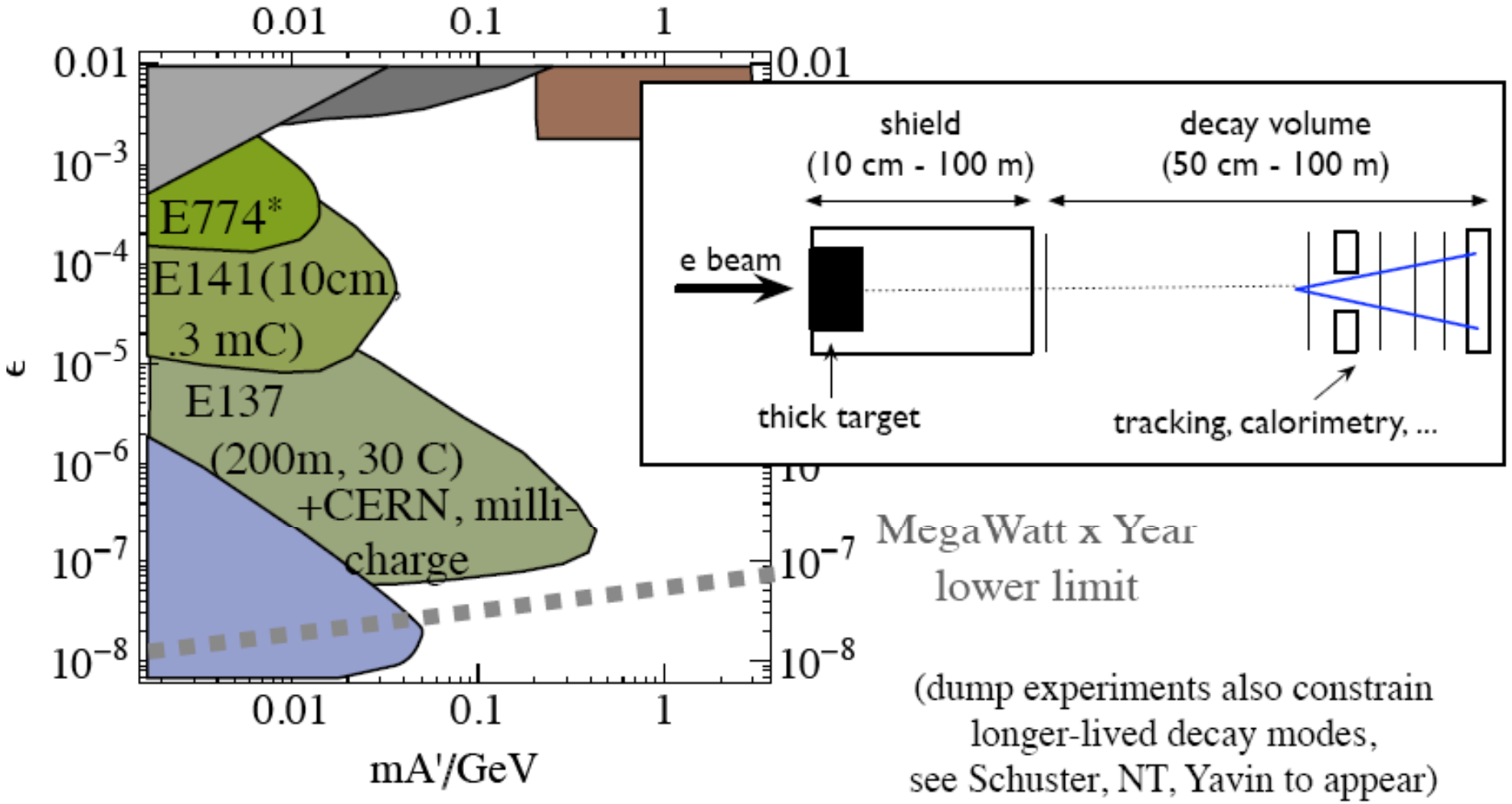


FIG. 1 (color online). *Left:* Existing constraints on an A'. Shown are constraints from electron and muon anomalous magnetic moment measurements, a_e and a_μ, the *BABAR* search for $\Upsilon(3S) \to \gamma\mu^+\mu^-$, three beam-dump experiments, E137, E141, and E774, and supernova cooling (SN). These constraints are discussed further in Sec. III. *Right:* Existing constraints are shown in gray, while the various lines—light green (upper) solid, red short-dashed, purple dotted, blue long-dashed, and dark green (lower) solid—show estimates of the regions that can be explored with the experimental scenarios discussed in Secs. IV A, IV B, IV C, IV D, and IV E, respectively. The discussion in Sec. IV focuses on the five points labeled "A" through "E." The orange stripe denotes the "*D*-term" region introduced in Sec. II A, in which simple models of dark matter interacting with the A' can explain the annual modulation signal reported by DAMA/LIBRA. Along the thin black line, the A' proper lifetime $c\tau = 80\ \mu$m, which is approximately the τ proper lifetime—see Eq. (11).

Searching in Dumps

Slide from N.Toro

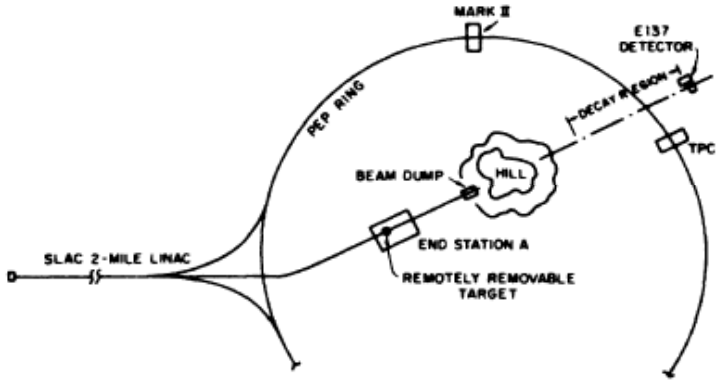


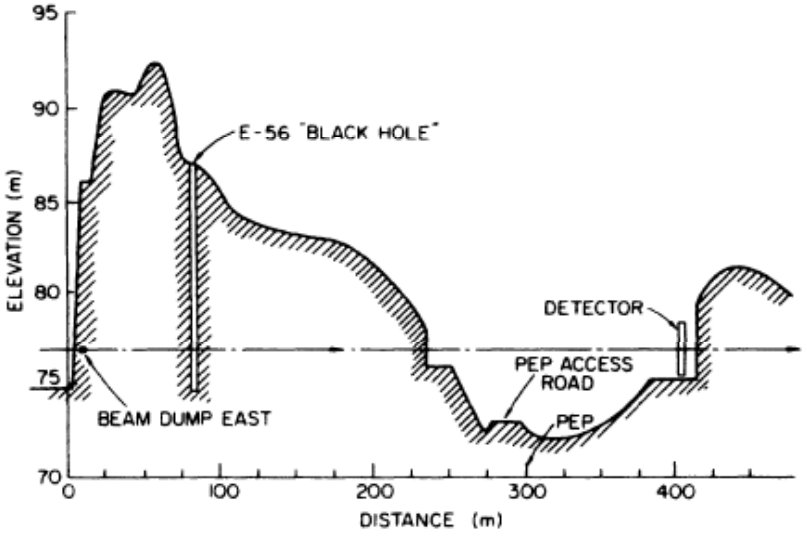
(dump experiments also constrain longer-lived decay modes, see Schuster, NT, Yavin to appear)

*E774: 20cm, .3 mC

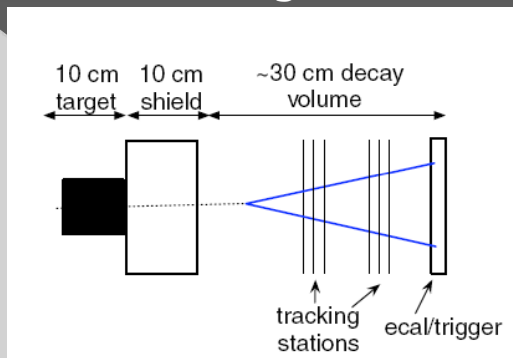
Beam Dump Experiments

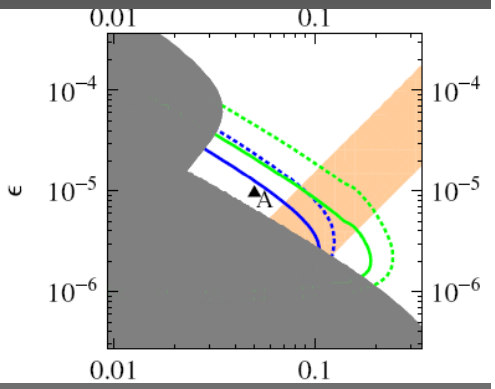
- Sample layout: SLAC E137, Bjorken et al, PRD38, 3375 (1988)





- Dumped ~30 Coulomb of 20-GeV electrons
- New scenario and reach analyzed in BEST (contours indicate sensitivity for 0.1-0.3C at electron energies





- JLAB/CEBAF electons : I<180uA (<6 GeV)
- JLAB/FEL : I<10mA at ~150MeV
- SLAC's 30C benchmark can be reached
  - -In ~2days for 6GeV and
  - -In ~1hour at 150MeV@FEL

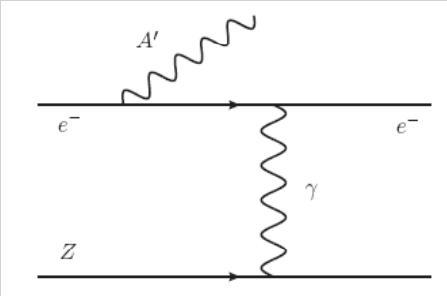
Upcoming JLAB experiments (in preparation)

- Wojtsekhowski, Bjorken et al (Hall A); JLAB Proposal PR-10-009 (**test run underway June-July 2010**)
- Thaler, Fisher, Ent (Berkley, MIT, JLAB): (LOI 10-006): Use gas jet target at JLAB FEL beam
- Jaros, Stepanian, Maruyama et al (Hall B photon dump)
- Baker, Afanasev, et al (Beam dumps: Hall A/C, FEL)
- See also the talk by Sarah Andreas (at DESY)

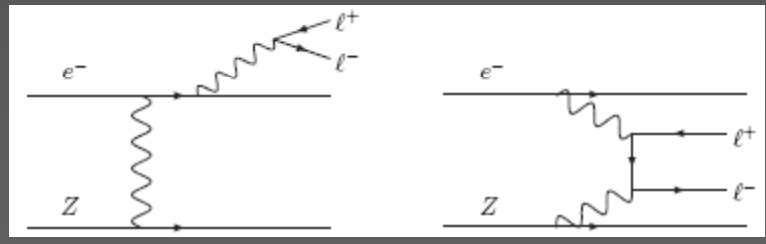
Search for a New Vector Boson A' Decaying to e^+e^-

Experiment JLAB E-10-009

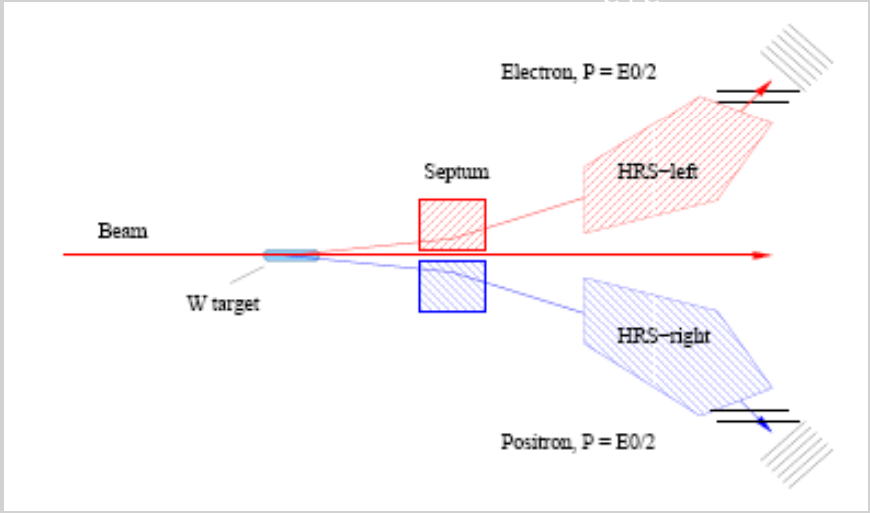
For details of planned experiment, see Essig et al, arXiv:1001.2557

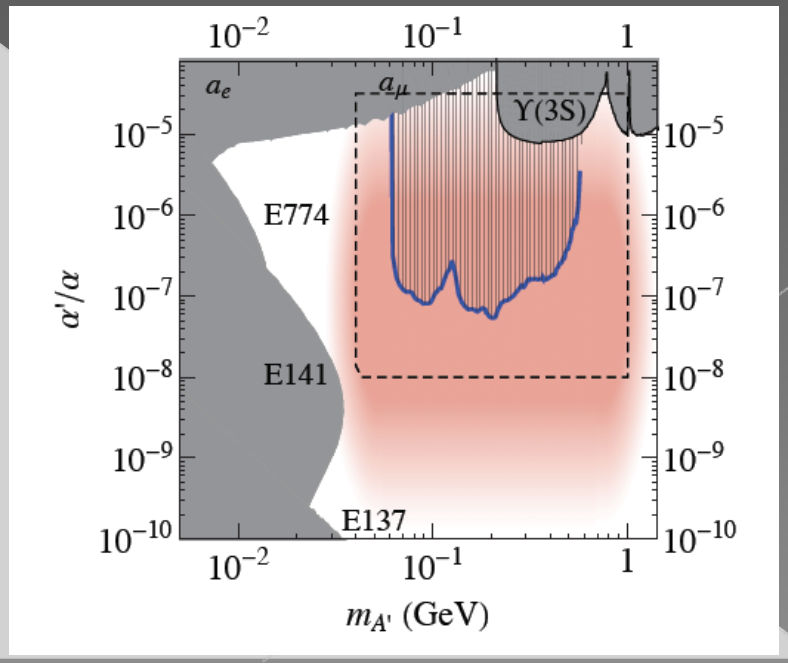


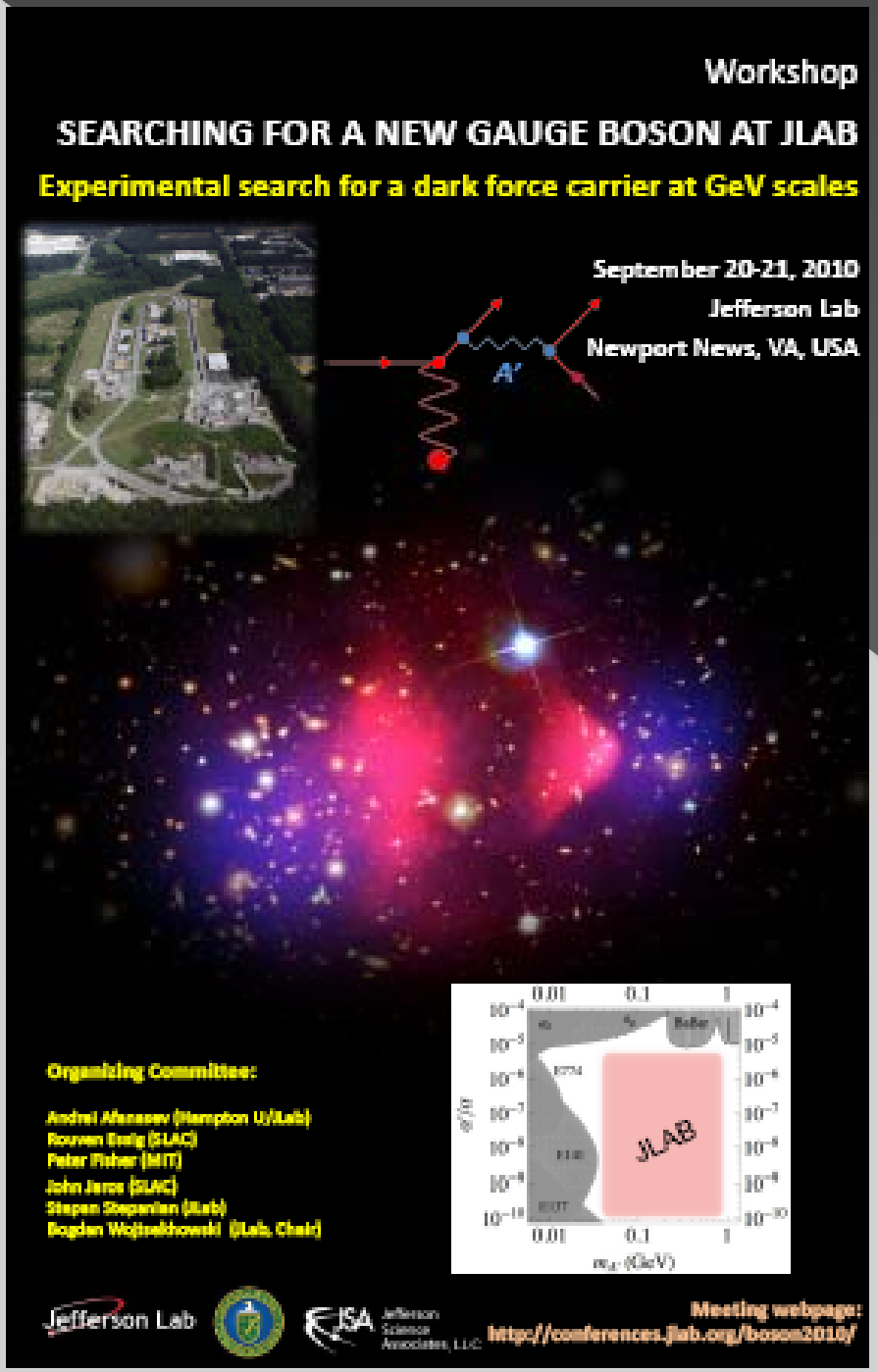
- A′ is produced in electron scattering on a fixed target with a charge Z, its decay into e+e- pairs is searched for (upper plot);
- Major background: Standard QED processes :Bethe-Heitler pairs



Experimental setup: W target, septum magnet, High-resolution spectrometers (HRS)
Rate of e+e- pair production is measured as a function of invariant mass W_{e+e-}







- The workshop will be held at Jefferson Lab later this year (September 20-21, 2010)
- Purpose: Planning experiments to search for a new gauge boson at MeV-GeV scales
  - Additional theoretical motivation is not needed at this stage (!)
  - Focused on experimental techniques, equipment and priorities in scheduling

Electrodynamics of Dark Matter

(AA, Carlson, in preparation)

Dark Compton Scattering, polarizability of WIMPS
in electromagnetc fields
Dark Delbruck effect:
Light absorption+dispersion at astrophysical distances

<- Photo-convertion of dark bosons
into electron-positron pairs

Dark Bethe-Heitler pair production:
Electron-positron pair production
on a dark field of a WIMP->

Discovery potential of fixed-target experiments

- Fixed-target experiments well suited to search for dark forces – high intensity
- Large parameter space requires multiple search strategies
  - Low coupling/mass: Beam dump experiments
  - High coupling/mass: standard wide-angle spectrometers (e.g. JLab)
  - Large intermediate region for new forward-geometry experiments to explore

Summary

- Newly observed astrophysics anomalies can be interpreted in terms of Dark-Matter particles at ~TeV scale and force-carrying particles at MeV-GeV scale
- This is within reach for JLAB
  - APEX experiment is running
  - More experiments being planned